



Accelerated Insertion of Materials – Composites



Presented at
Aeromat 2002
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**Jointly accomplished by BOEING and the U.S. Government
under the guidance of NAST**

This program was developed under the guidance of Dr. Steve Wax and Dr. Leo Christodoulou of DARPA. It is under the technical direction of Dr. Ray Meilunas of NAVAIR.



The AIM-C Team



- Boeing – Seattle and St. Louis – AIM-C CAT, Program Management
- Boeing – Canoga Park – Integration, Propagation of Errors
- Boeing – Philadelphia – Effects of Defects

CMT

- Convergent Manufacturing Technologies – Processing
- Cytec Engineered Materials – Constituent Materials, Supplier



- Materials Sciences Corporation – Structural Analysis Tools
- MIT – Dr. Mark Spearing – Lamina and Durability
- Northrop Grumman – Bethpage – Blind Validation
- Northrop Grumman – El Segundo – Producibility Module
- Stanford University – Durability – Test Innovation



NORTHROP GRUMMAN





AIM-C Alignment Tool



The objective of the AIM-C Program is to provide concepts, an approach, and tools that can accelerate the insertion of composite materials into DoD products

AIM-C Will Accomplish This Three Ways

Methodology - *We will evaluate the historical roadblocks to effective implementation of composites and offer a process or protocol to eliminate these roadblocks and a strategy to expand the use of the systems and processes developed.*

Product Development - *We will develop a software tool, resident and accessible through the Internet that will allow rapid evaluation of composite materials for various applications.*

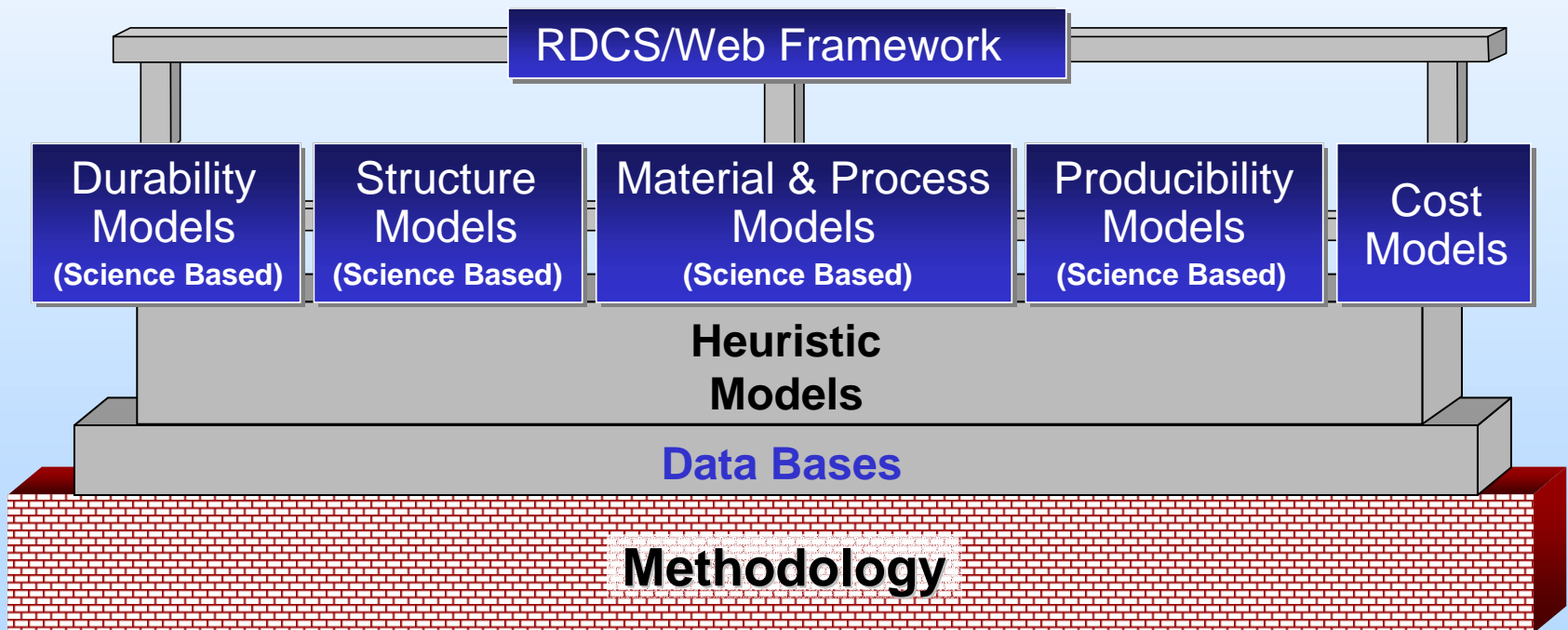
Demonstration/Validation - *We will provide a mechanism for acceptance by primary users of the system and validation by those responsible for certification of the applications in which the new materials may be used.*



The Plan



- Incorporate methodology into an interface that guides the user and tracks the progress of technology maturation to readiness
- Deliver software in steps toward a useable system as analysis modules are completed
- Demonstrate capability through system validation, compelling technical demonstration, and a 'blind validation' to insure usability



RDCS – Robust Design Computational System



How Will the System Be Used?

NAVAIR



Web-Driven

- Accessed via Internet
- Used via Internet
- Application file local
- DOME enabled
- Modules available anywhere
- Configuration controlled by user
- Application file contains configuration info

PROs most flexible

Web-Based

- Downloaded from Internet
- Used locally to create application file
- Application file local
- Modules & S/W available few locations
- Configuration controlled by application file
- DOME enables remote access to modules

PROs most controlled

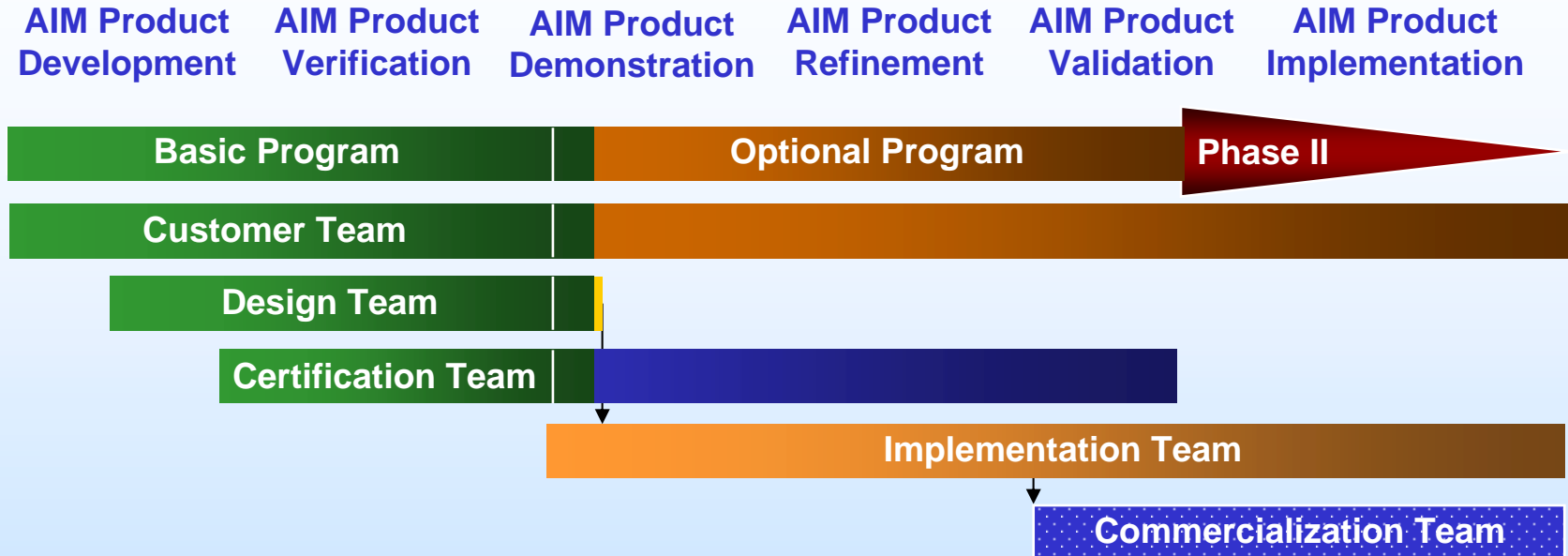
Stand Alone

- Accessed locally
- Used locally to create application file
- Application file local
- Modules & S/W available locally
- Configuration controlled by application file

PROs may be only way for classified programs to use AIM-C



Technology Transition Plan



Customer Team – To ensure that the product meets the needs of the funding agents

Design Team – To ensure acceptance among users in industry

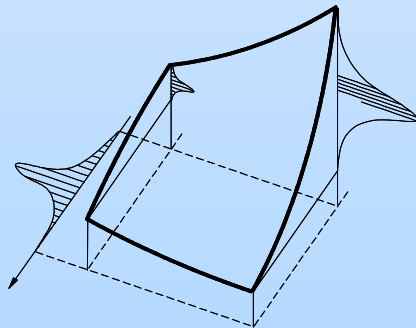
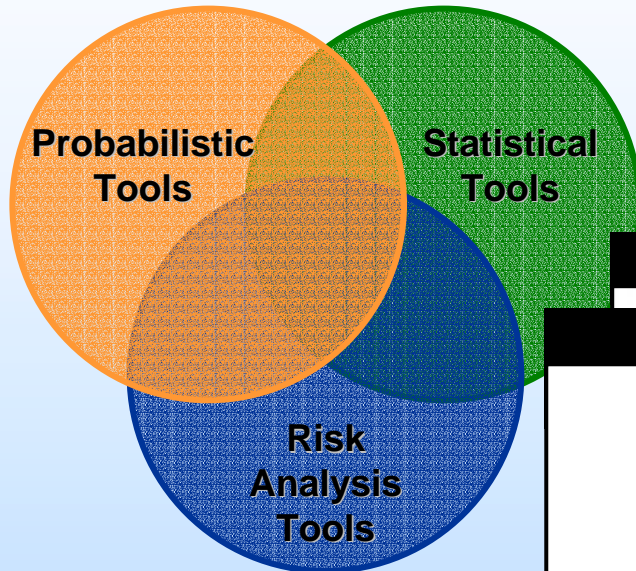
Certification Team – To ensure acceptance among the certification agents for structures

Implementation Team – To ensure acceptance among the user community

Commercialization Team – To ensure commercial support of users



Understanding Uncertainty – The Benefit of Linked Simulation Tools and Methodology

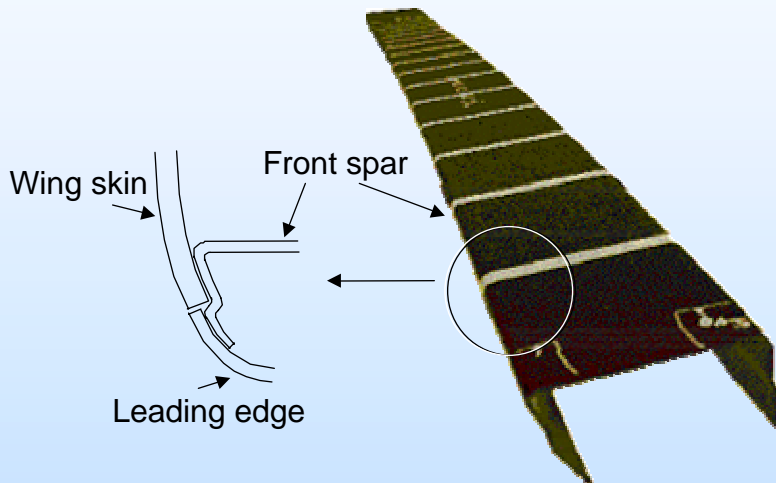


Coupon Failure Modeling Errors and Uncertainties				
Producibility Uncertainty				
Prepreg Module Uncertainty Considerations				
Resin Module Uncertainty Considerations				
Modeling of the Process				
	Inherent variations associated with physical system or the environment (Aleatory uncertainty) Also known as variability, stochastic uncertainty E.G. manufacturing variations, loading environments	Uncertainty due to lack of knowledge (Epistemic uncertainty) inadequate physics models information from expert opinions.	Known Errors (acknowledged) e.g. round-off errors from machine arithmetic, mesh size errors, convergence errors, error propagation algorithm	Mistakes (unacknowledged errors) human errors e.g error in input/output, blunder in manufacturing
Temperature Boundary Conditions	Variation in temperature throughout an autoclave; variation in bagging thickness across part	Modeling of heat transfer coefficient of autoclave includes pressure effect but not shielding of part. Assumptions made about tool-part resistance.	Convergence of mesh must be checked. Time-steps and temperature steps must be small enough.	Errors in setup files, and other initialization procedures. Errors/bugs in code.
Tool Part Interaction	Part to part and point to point variations in tool finish and application of release agent	Tool-part interaction is very complex, and very local effects may at times be significant	Current model of tool-part interaction is too simple for large parts on high CTE tools.	Errors in calibrating the tool-part interaction
Layup	Variation in lay-up during hand or machine lay-up.	The layers are smeared within an element and it is assumed that the smeared response is representative		Error in defining layup, or alternatively errors in the manufactured part compared to model
Residual Stresses	Many parameters can affect residual stress: local fiber volume fraction, ...	Micro-stresses are considered to be independent of meso-stresses; there are few independent measurements of residual stress.	The formulation is believed to be most accurate when the cure cycle temperature is higher than the T _g . Otherwise the residual stress calculated can be an overestimate.	Errors in material property definition, errors in coding, errors in integrating process and structural models.



AIM-C CAT Benefits: COMPRO Integration with Robust Design Computational System (RDCS)

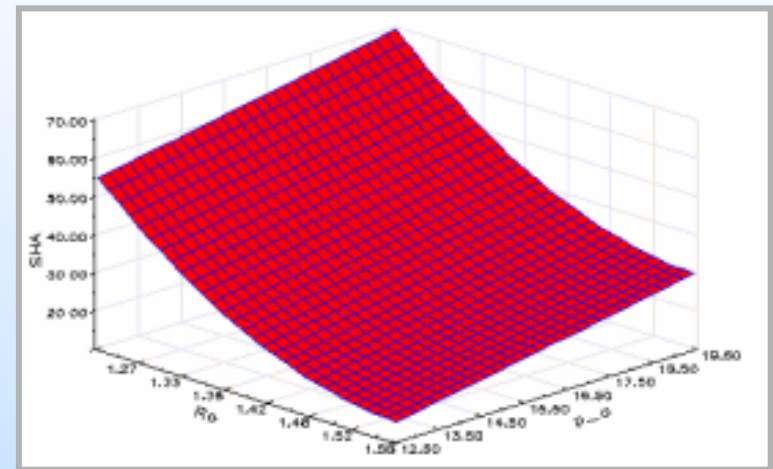
767-400 Raked Wingtip Front Spar
DOE Sensitivity Analysis



Conventional Approach

- 32 - Runs for simple DOE
- 4 - Months calendar time to set-up and solve
- Computer (time) intense
- 216 - Hrs actual labor to complete
- Labor-intense data reduction

RDCS Sensitivity Analysis Plus
Design Scan



Integrated with RDCS

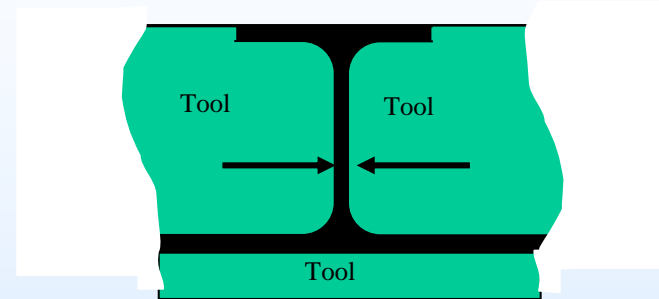
- 127 - Runs for sensitivity analysis and design scan
- 1-2 weeks calendar time to set-up and solve
- User isolated from intense interaction with multiple codes
- 28 - Hrs actual labor to complete
- Automated data reduction and graphics



Architecture Example Statistical Evaluation

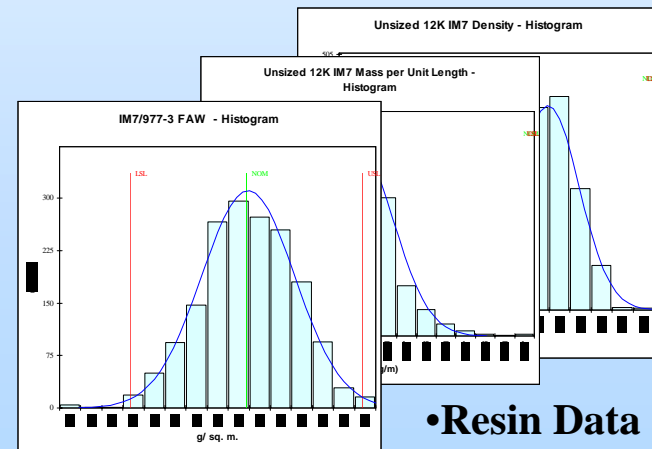


Existing tolerance
requirements on process



- Closed mold tolerances
- Structural tolerances
- Electromagnetic tolerances

Insert New Areal Weight
Tape Material

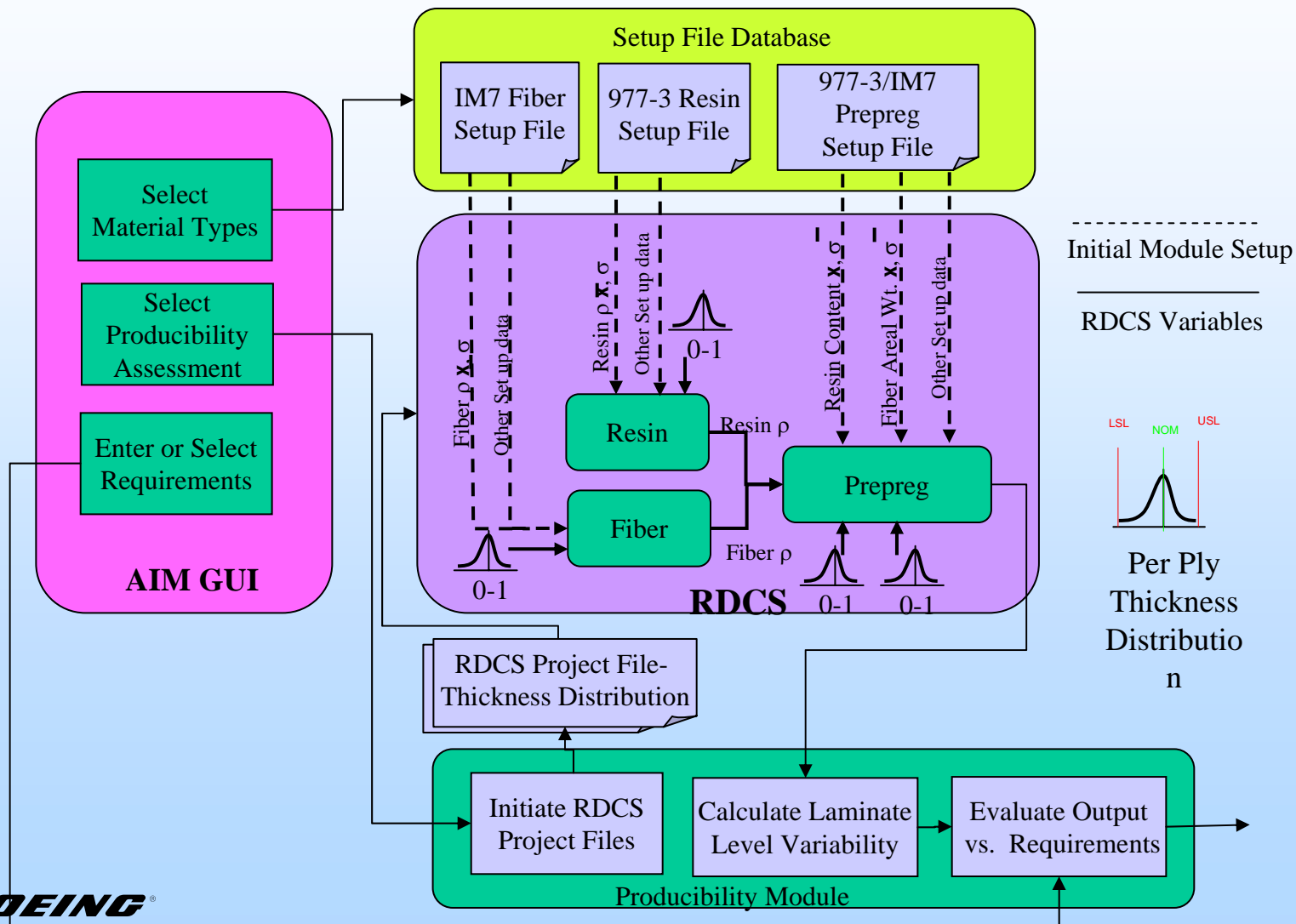


- Resin Data
- Fiber Data
- Prepreg Data



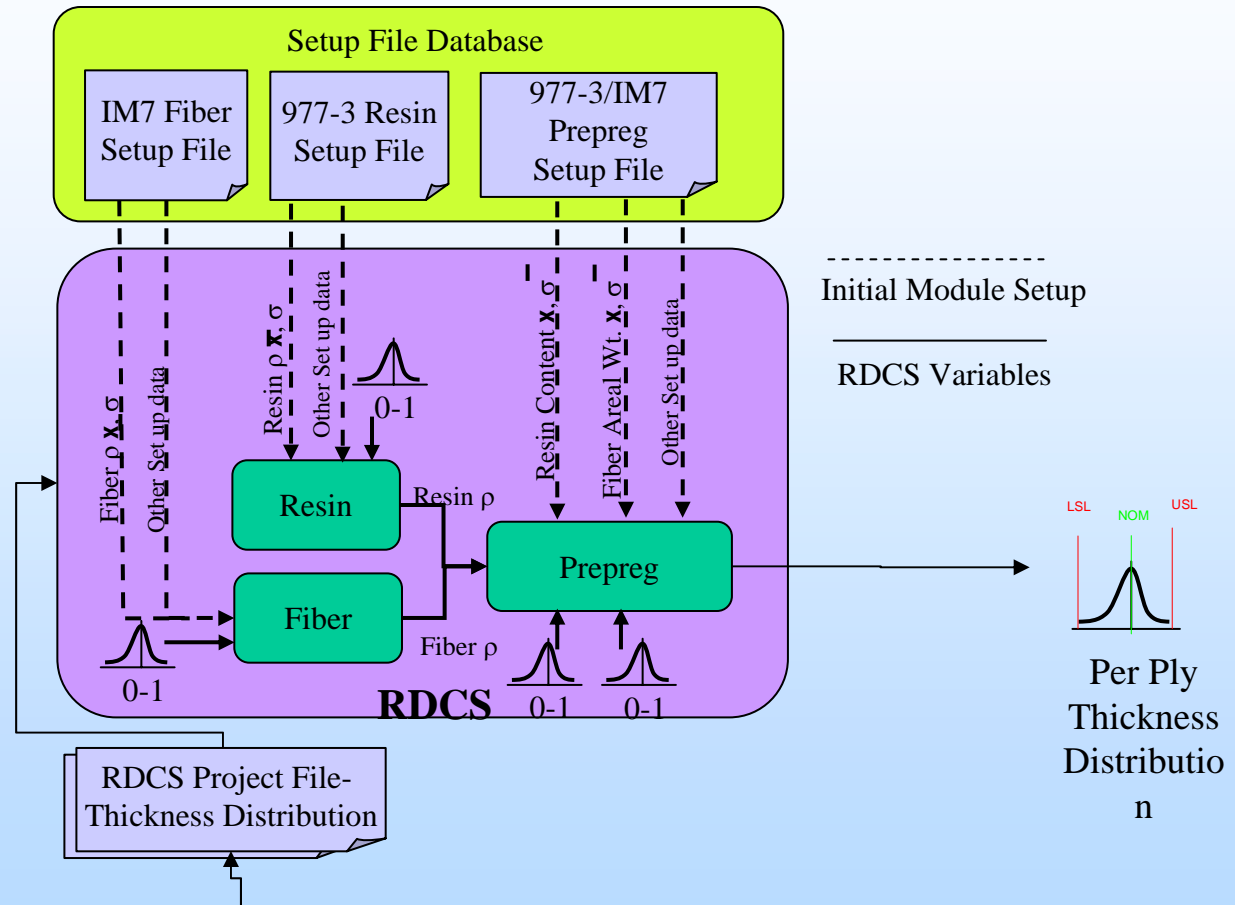


Architecture Example Statistical Evaluation





Statistical Evaluation RDCS Exercise





Statistical Evaluation RDCS Exercise Input Values



Specification Extremes

	Input Variable Description/Name	Units	Source Module	Low	High.
A	Resin Density (est)	g/cc	Resin	1.27	1.31
B	Fiber Density	g/cc	Fiber	1.75	1.81
C	Fiber Areal Weight	g/sq. m.	Prepreg	280	300
D	Resin Content	wt. fract.	Prepreg	0.30	0.34

Mean and Std. Deviation

	Input Variable Description/Name	Units	Source Module	Average	St.Dev.
A	Resin Density (est)	g/cc	Resin	1.290	(2)
B	Fiber Density (1)	g/cc	Fiber	1.781	(2)
C	Fiber Areal Weight (1)	g/sq. m.	Prepreg	289.7	(2)
D	Resin Content (1)	wt. fract.	Prepreg	0.3231	(2)

- (1) From Supplier Database 500+ data points in all cases
- (2) Supplier proprietary



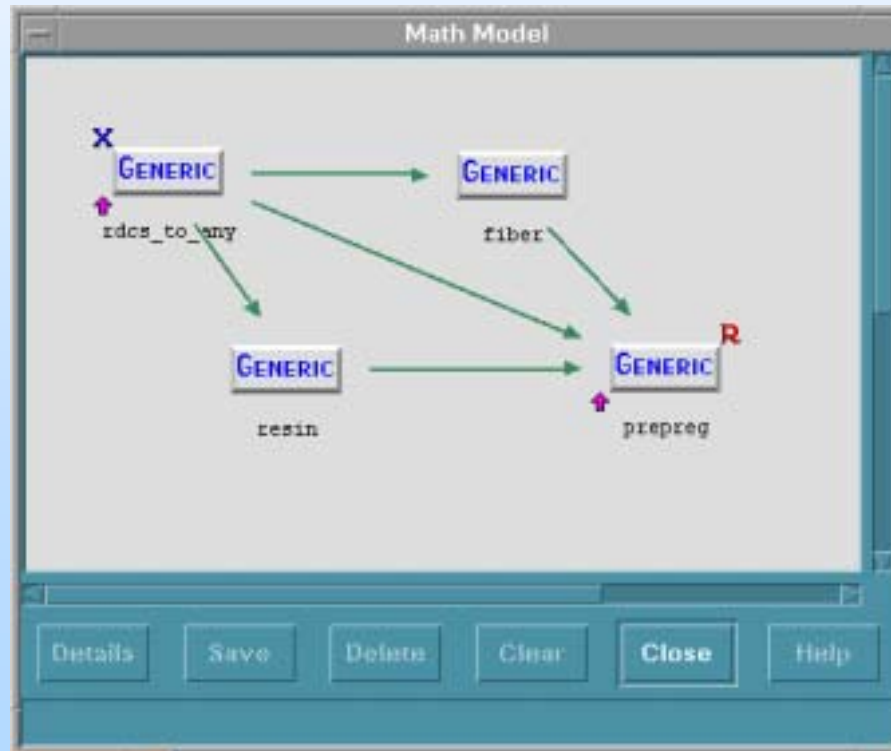
Statistical Evaluation

RDCS Exercise

RDCS Math Model



Demo 4:	fiber, resin, prepreg			Location		
	demo4_07	1000 runs	simulation	CP, CA	split	fiber, resin, prepreg
		80 runs	design space scan	CP, CA	split	fiber, resin, prepreg
	prepreg05	1000 runs	simulation	STL	combined	fiber, resin, prepreg
		80 runs	design space scan	STL	combined	fiber, resin, prepreg

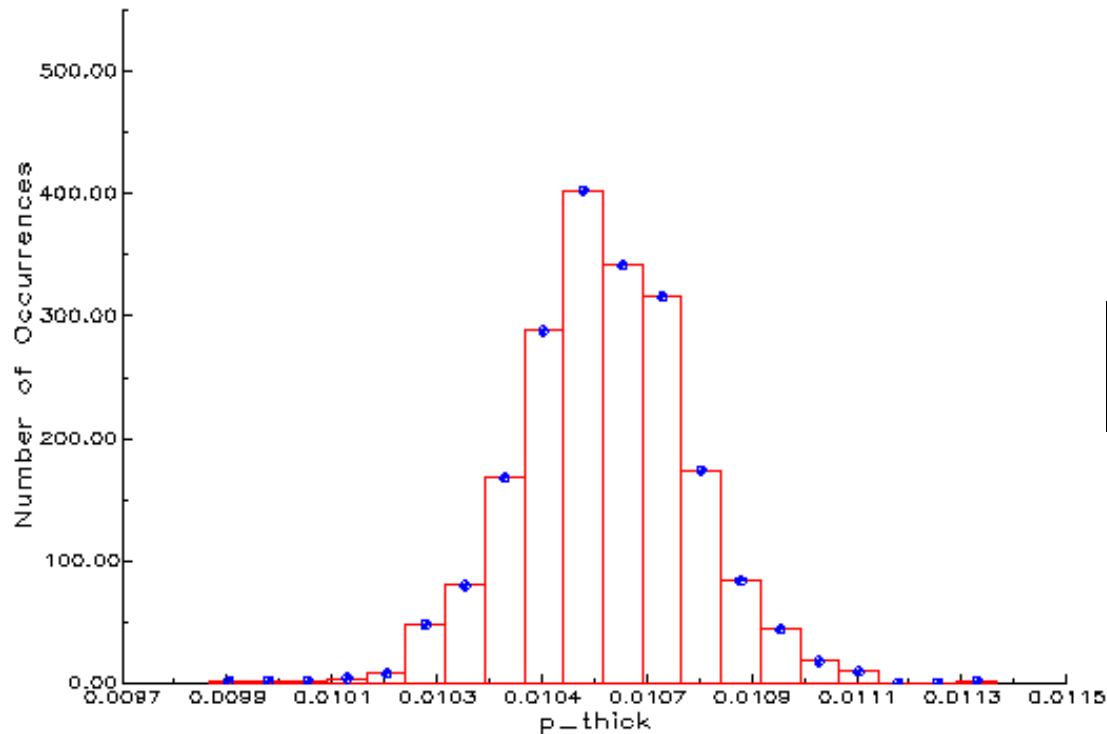




Statistical Evaluation RDCS Exercise Output



Simula: demo4_07
Instance Name: sim1



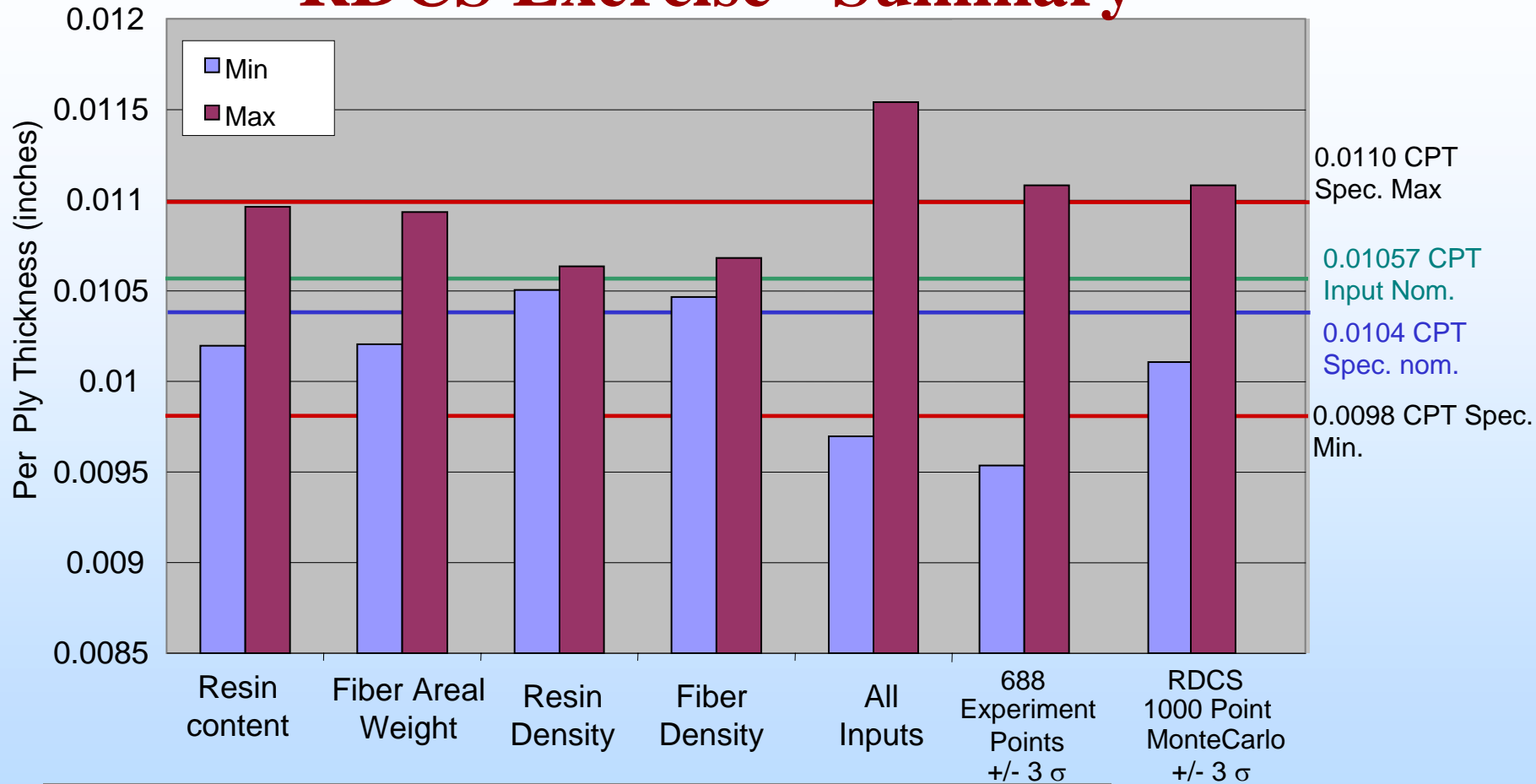
Canoga Park (SUN)

Normal	
Mean	0.01057
Std Dev	0.00016

Histogram
sim1: 1000 Monte Carlo Simulations
Max: 1.1242e-02 Min: 9.8159e-03 Average: 1.0569e-02
Standard Dev: 1.8408e-04 (2.6799e-04) Coef. of Var: 1.5522e-02



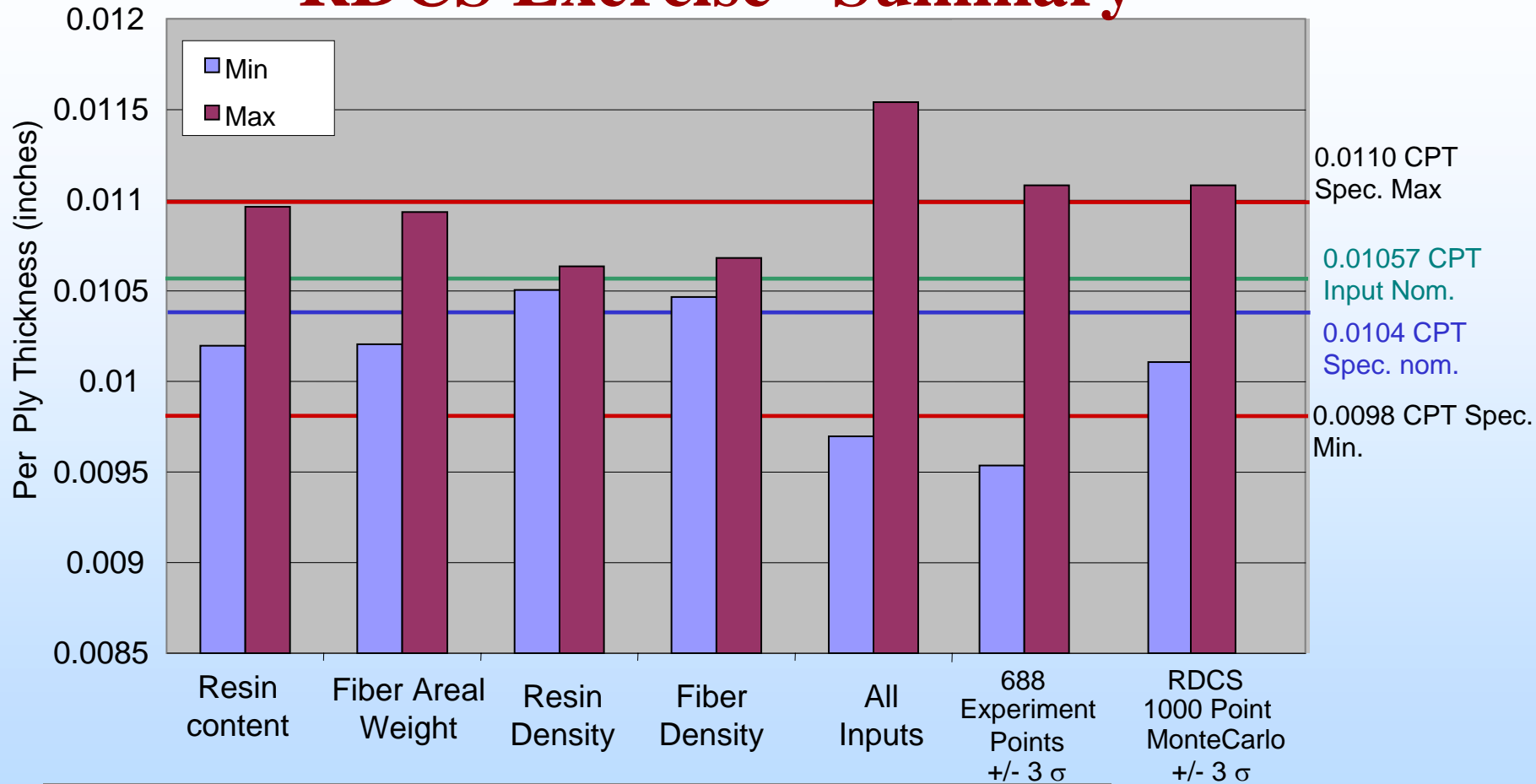
Statistical Evaluation RDCS Exercise - Summary



- Individual Effects within CPT Specification
- Worst Case Combined Effects Outside CPT Specification
- Probabilistic Run Agrees with Experimental Data on High End



Statistical Evaluation RDCS Exercise - Summary



- Individual Effects within CPT Specification
- Worst Case Combined Effects Outside CPT Specification
- Probabilistic Run Agrees with Experimental Data on High End



Statistical Evaluation RDCS Exercise - Summary



Data from 12 test panels (3 Material Batches) Evaluated in Detail

- **Significant Resin Loss Occurring During Panel Fabrication**
- **Resin Loss Factored into Specification CPT Levels**
- **Small Panel Area to Perimeter Ratio (Resin Edge Bleed)**



Process Development Cure Window Exploration



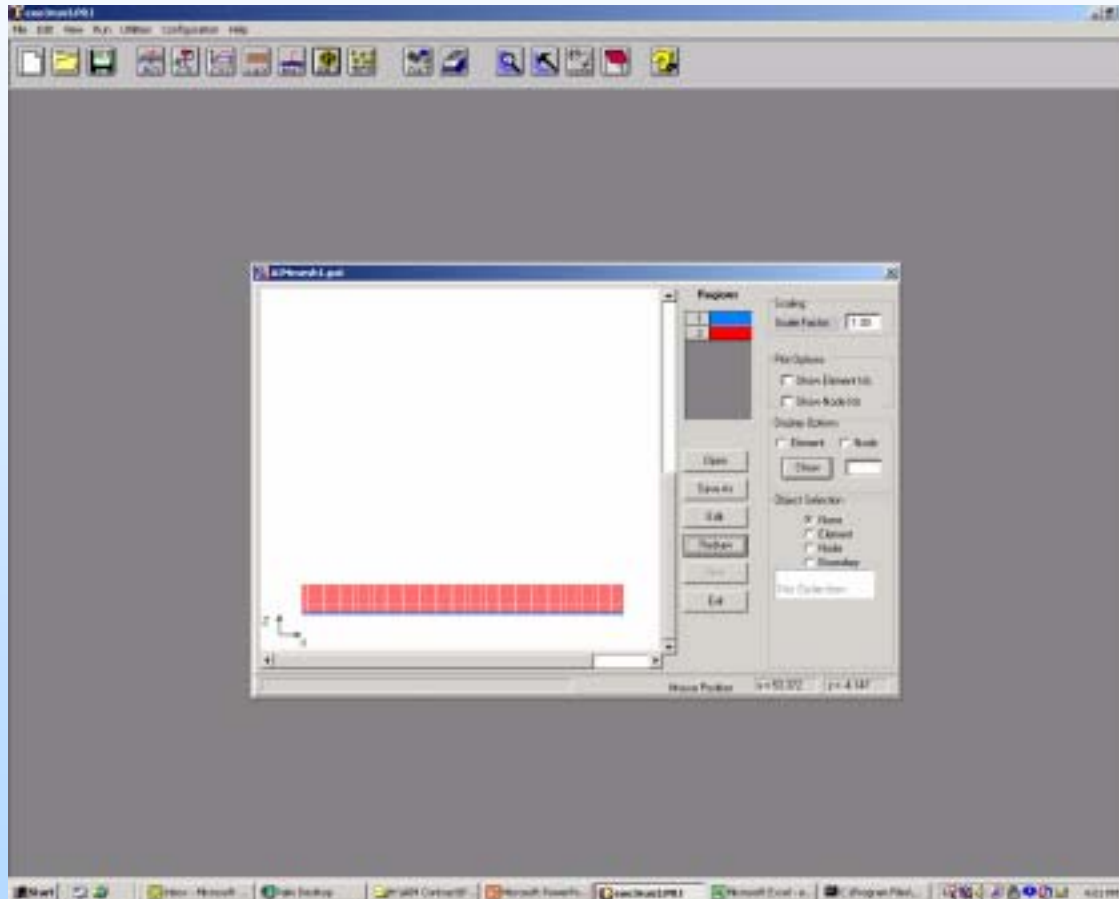
- Objective – Exercise process module with various thicknesses, material types, and cure cycles to determine exotherm occurrences, Compare to data where available.



Process Development Cure Window Exploration



AIM Processing Module (Driven through COMPRO)

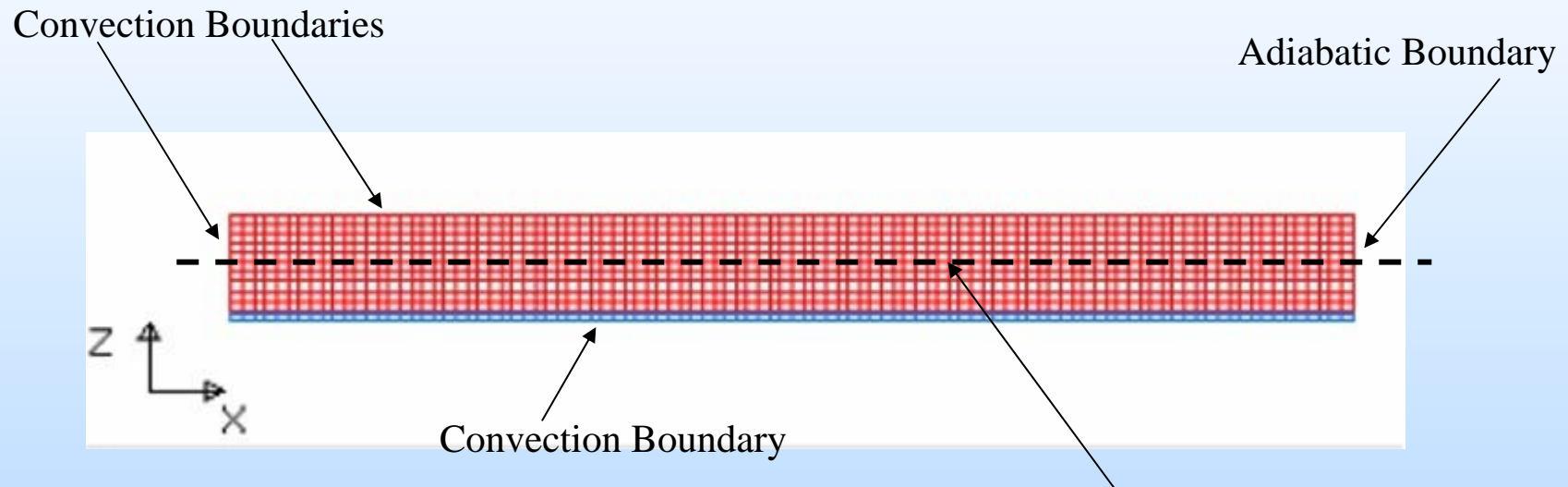




Process Development Cure Window Exploration



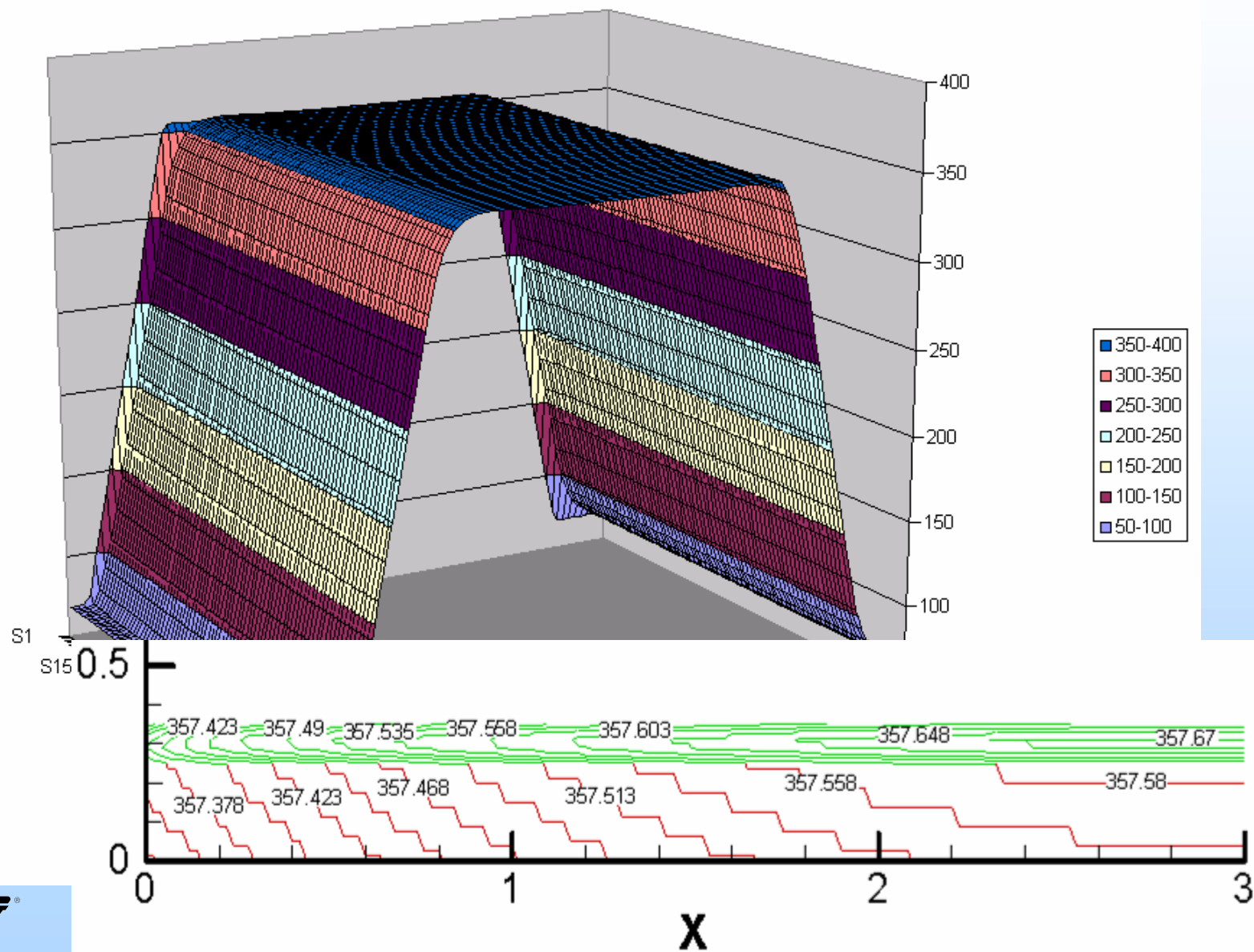
5" thick part on 0.5" thick Invar tool



- Part temperature data exported from model vs. time along part center line
- Surface Plot of Temperature and CL position vs. time generated
- Maximum temperature time determined
- Temperature Profile vs. X and Z position exported and plotted

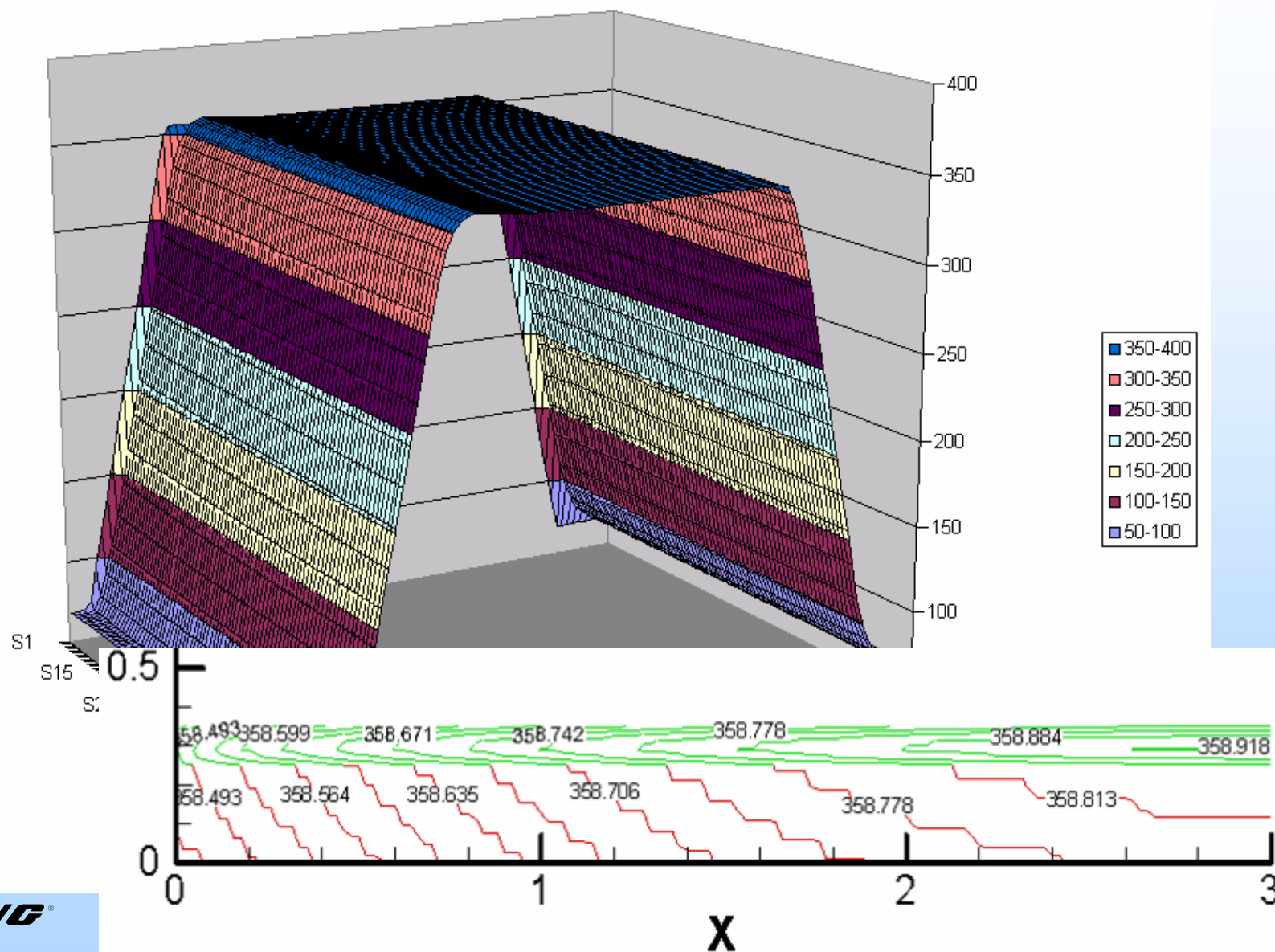


977-3 0.1" thick



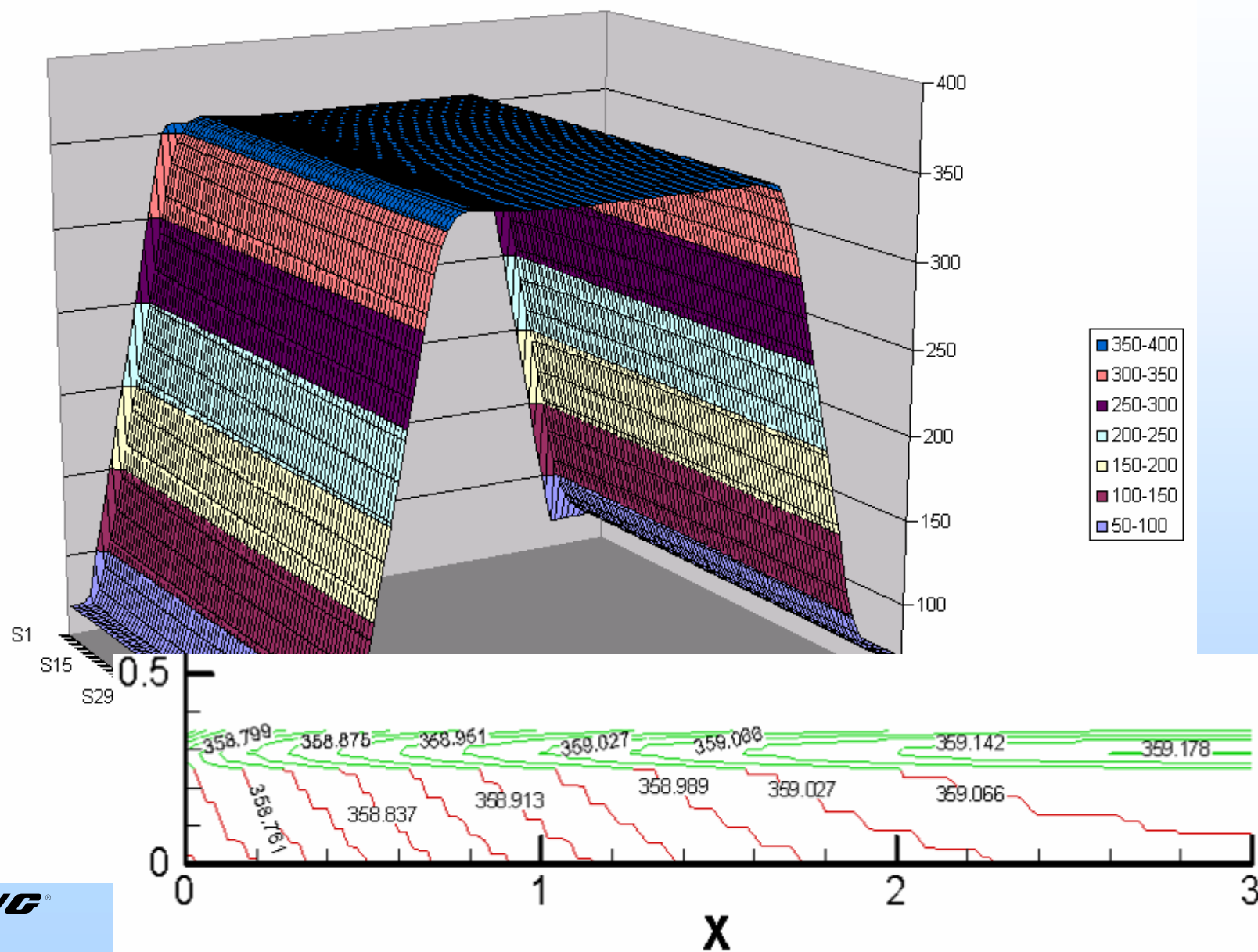


977-3 w/8552 kinetics & Hrx 0.1" thick



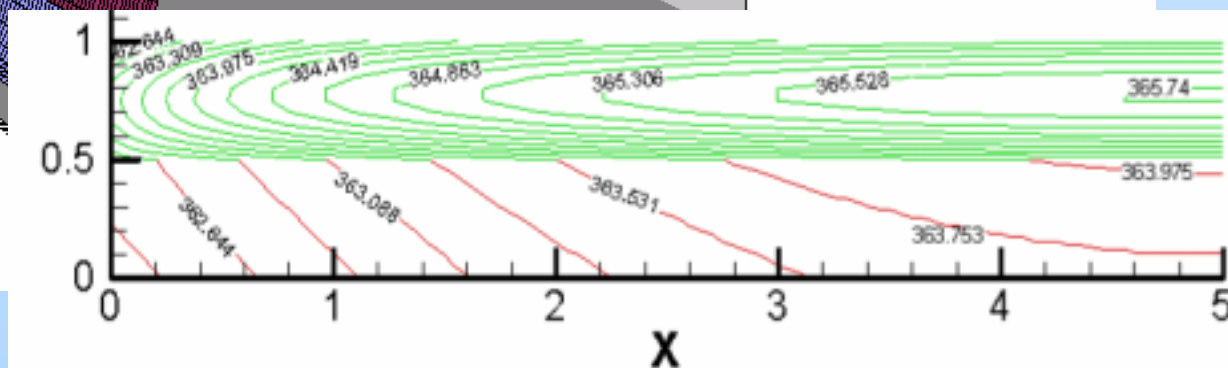
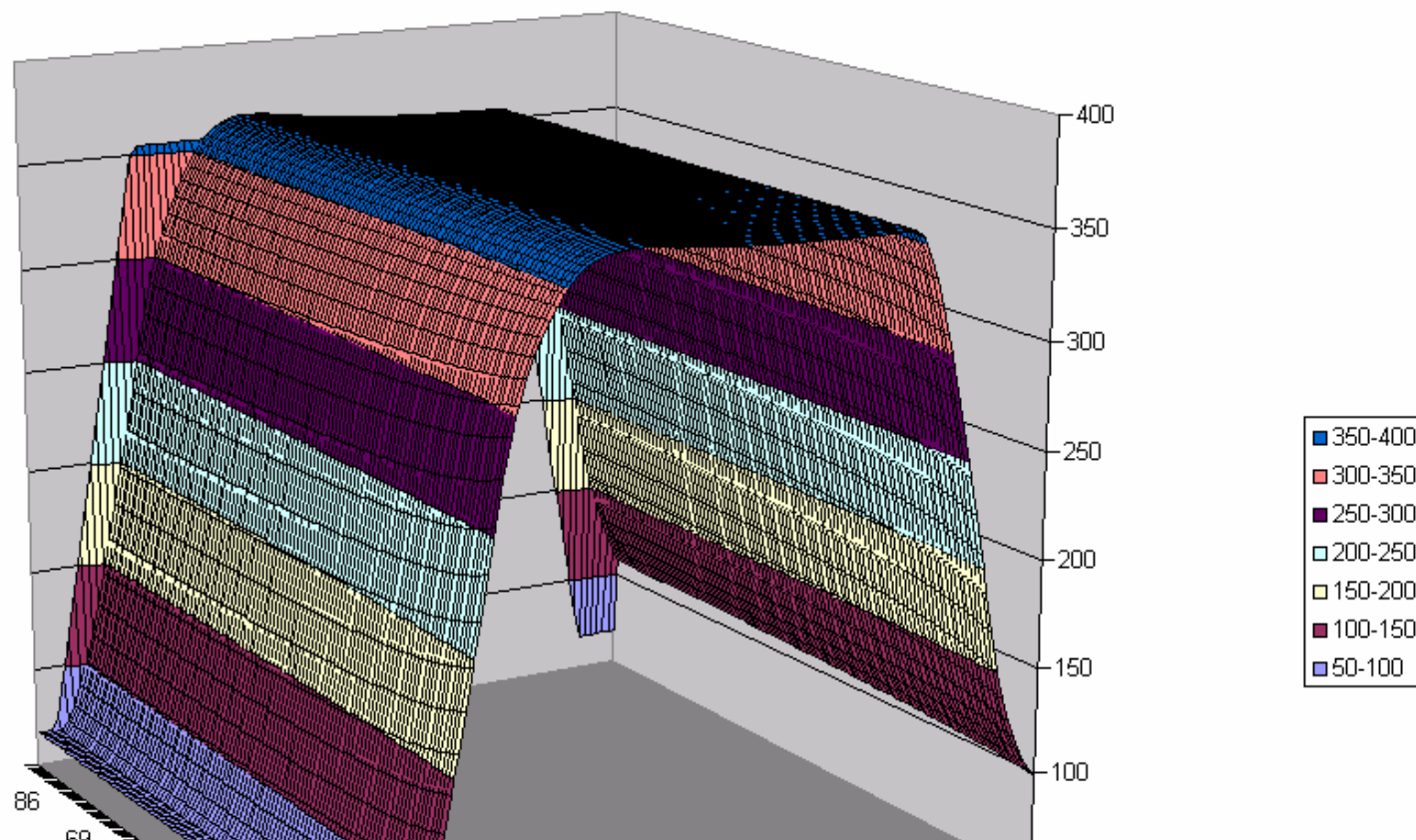


977-3 w/8552 kinetics & 977-3 HRx 0.1" thick



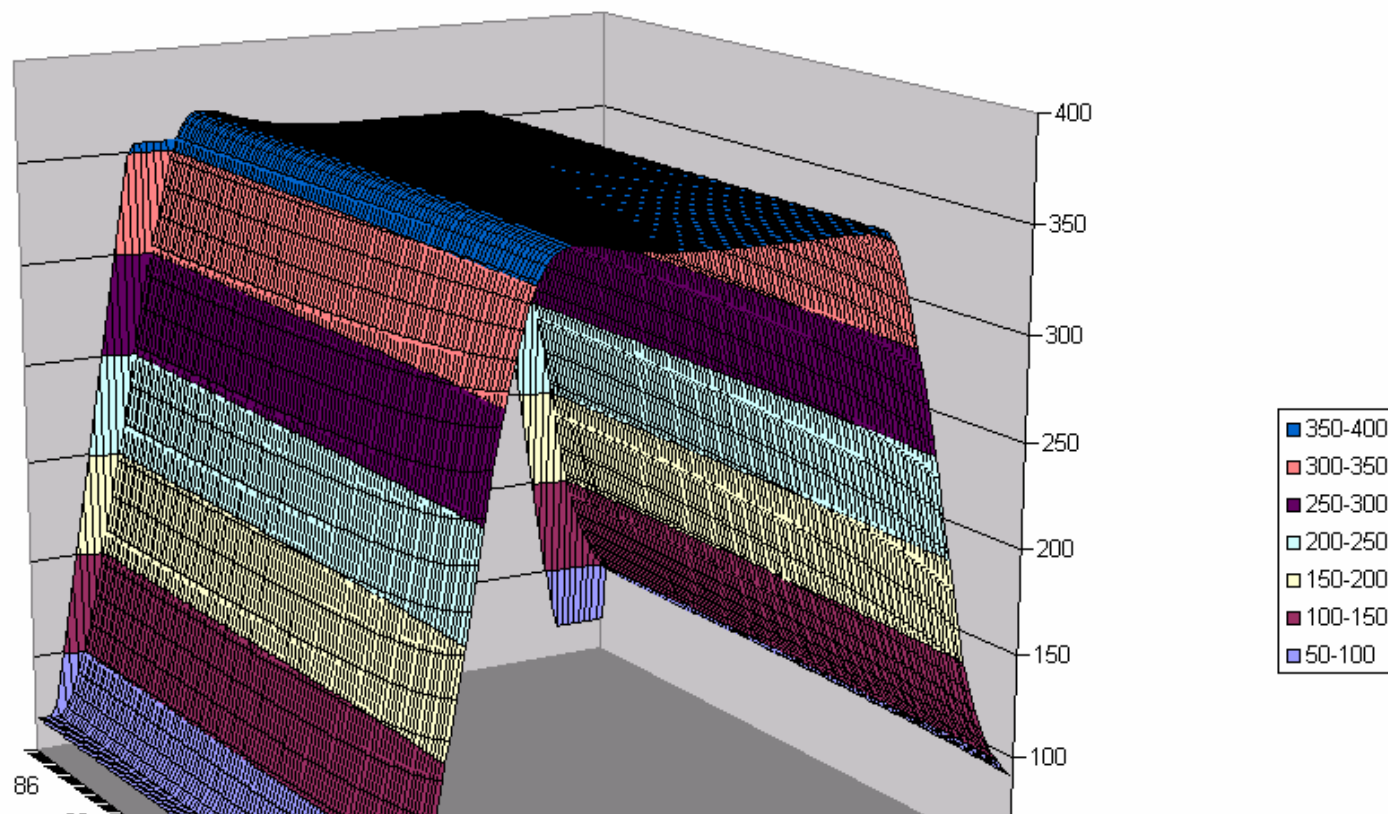


977-3 0.5" thick

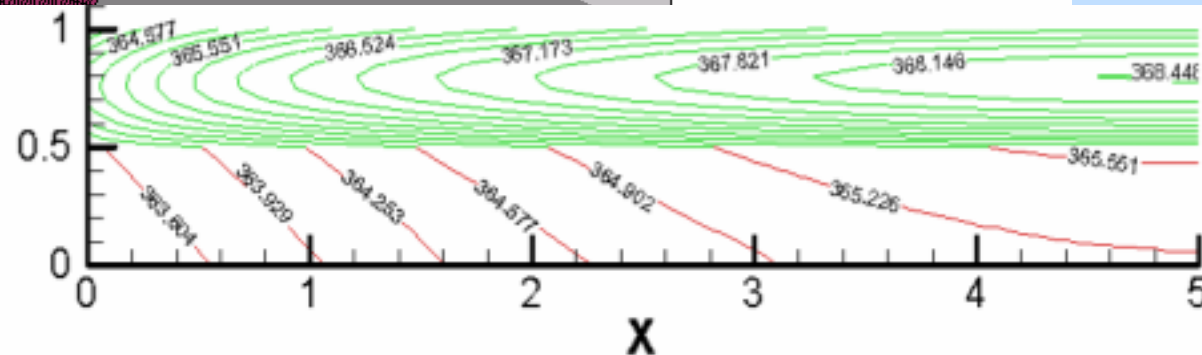




977-3 w/8552 kinetics & Hrx 0.5" thick

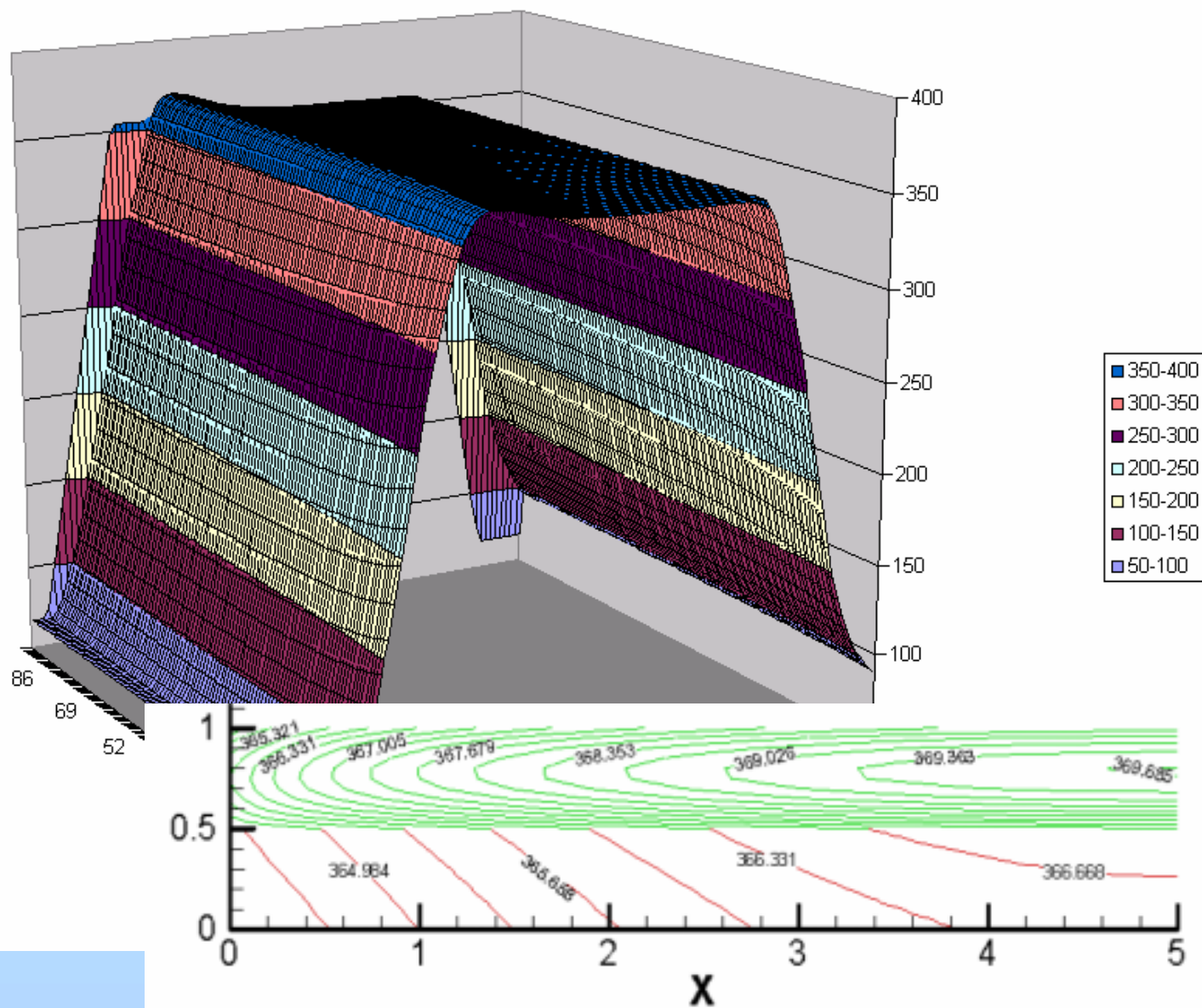


86
69
52
35
18



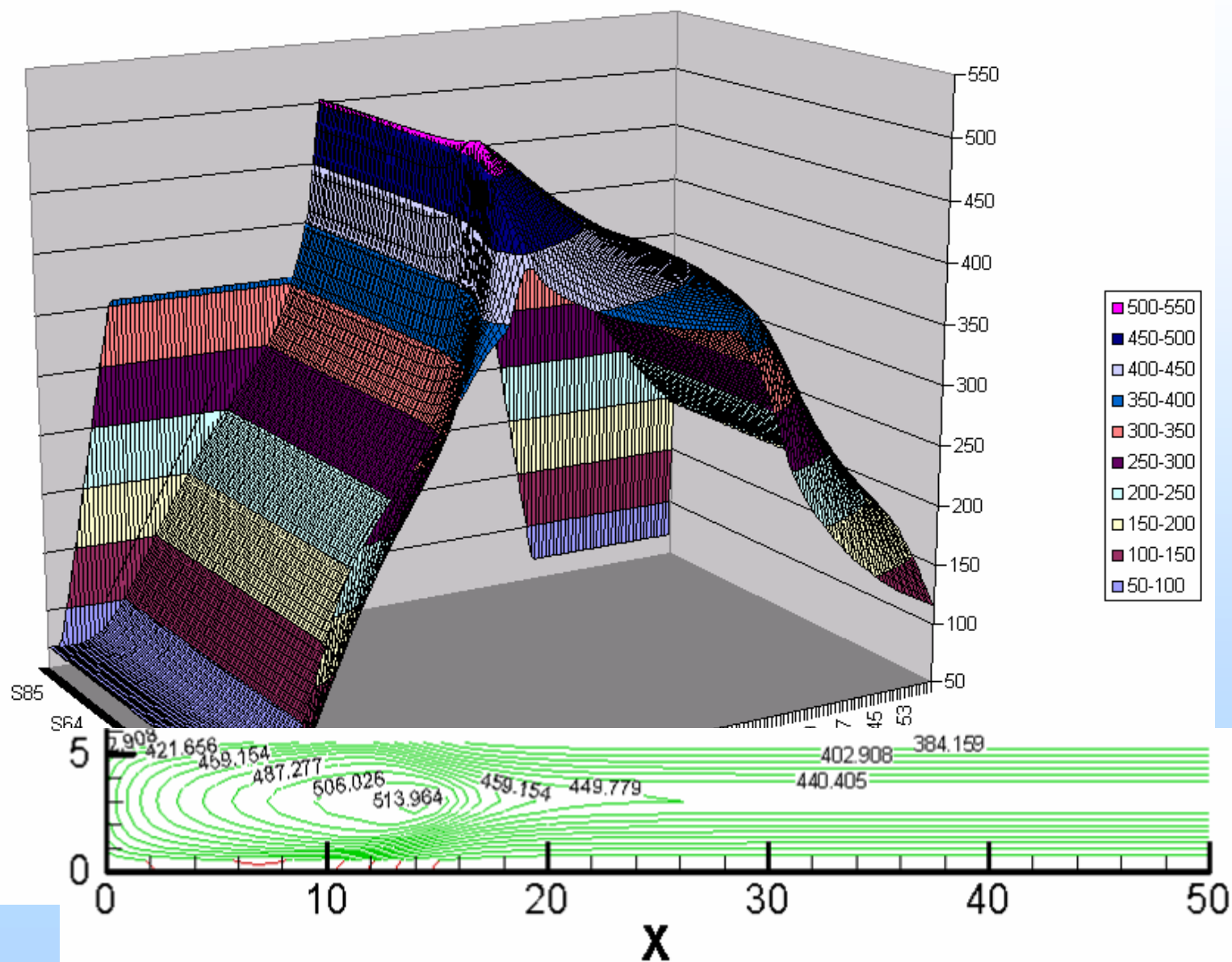


977-3 w/8552 kinetics & 977-3 HRx 0.5" thick



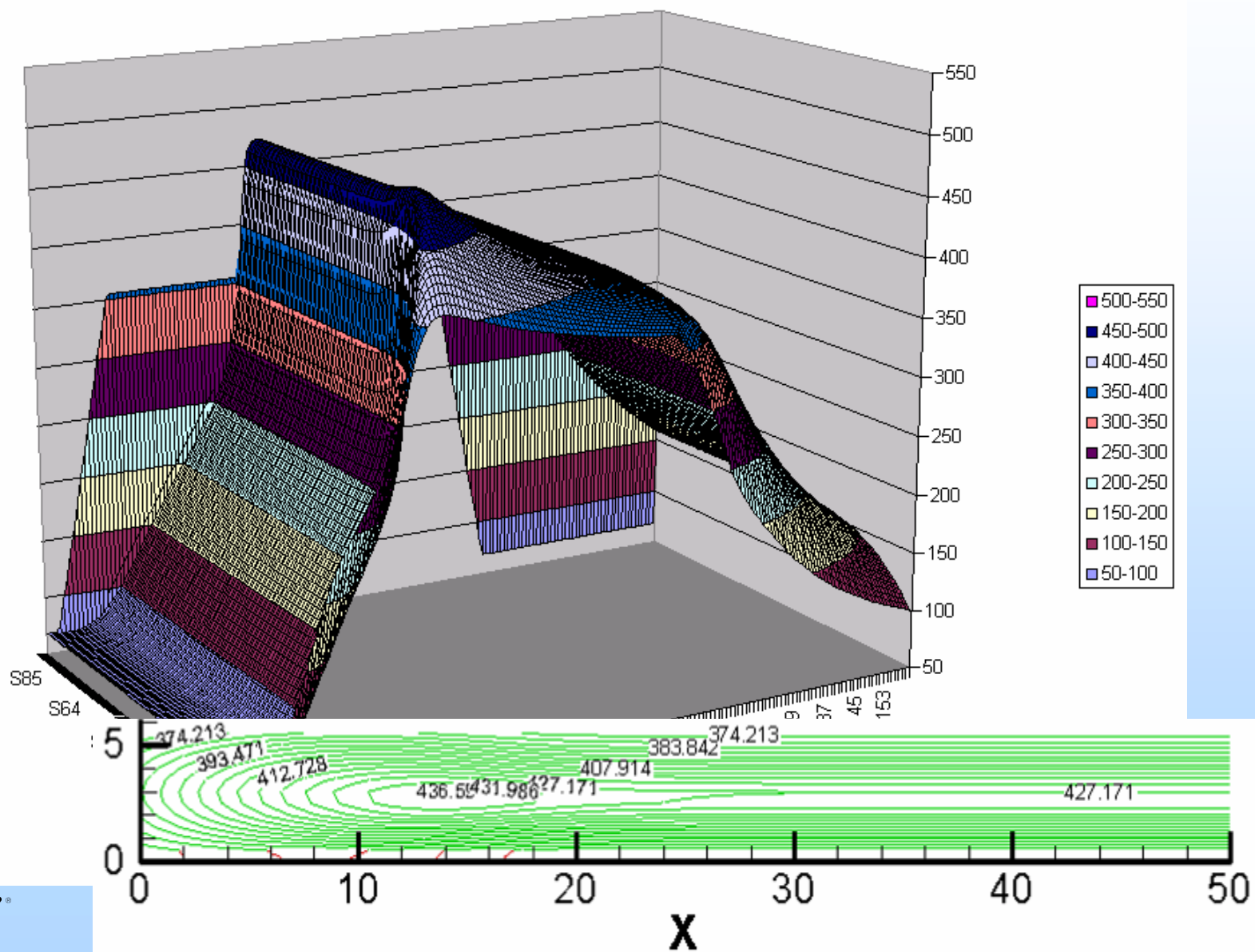


977-3 5" thick



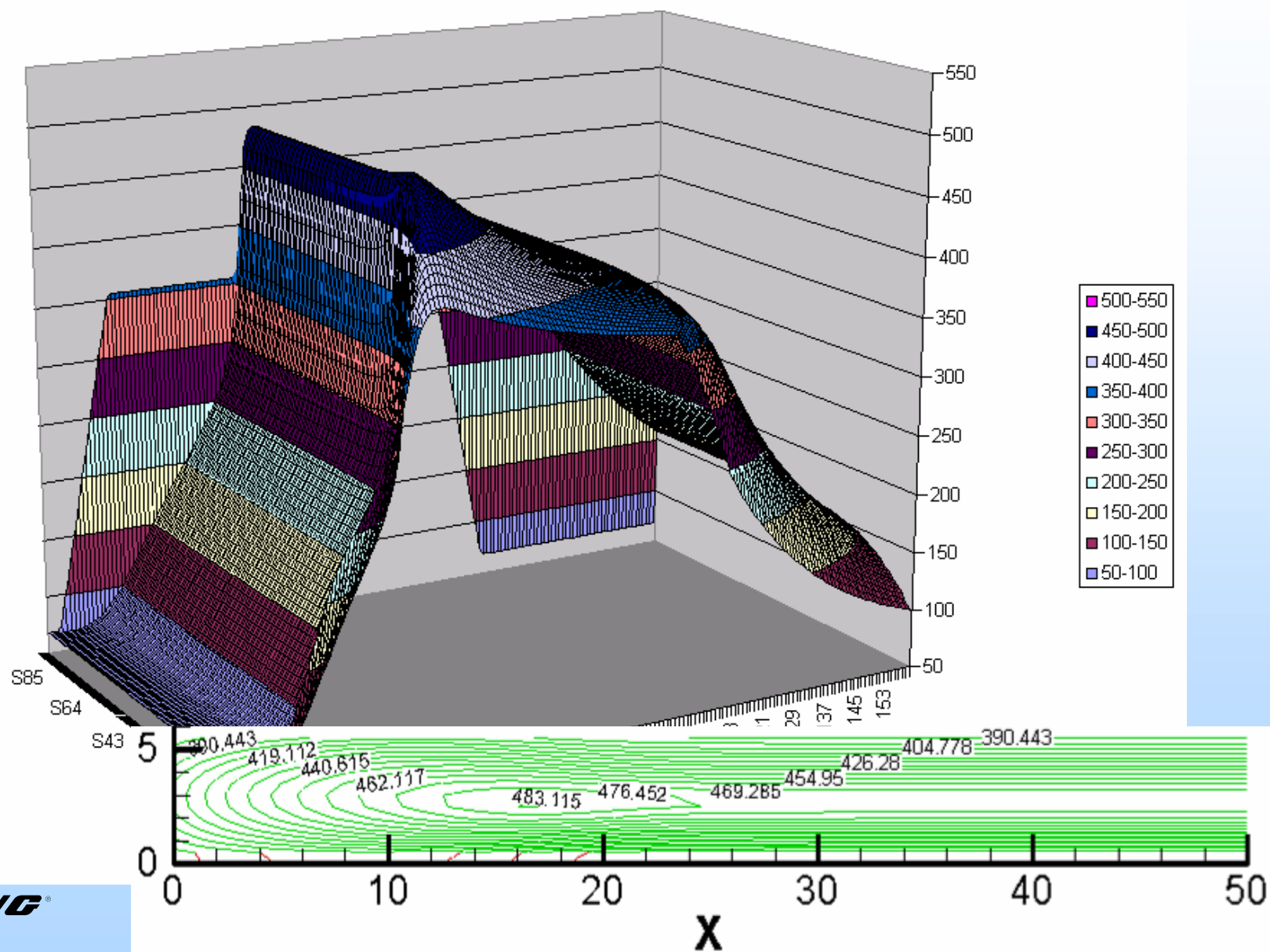


977-3 w/8552 kinetics & Hrx 5" thick



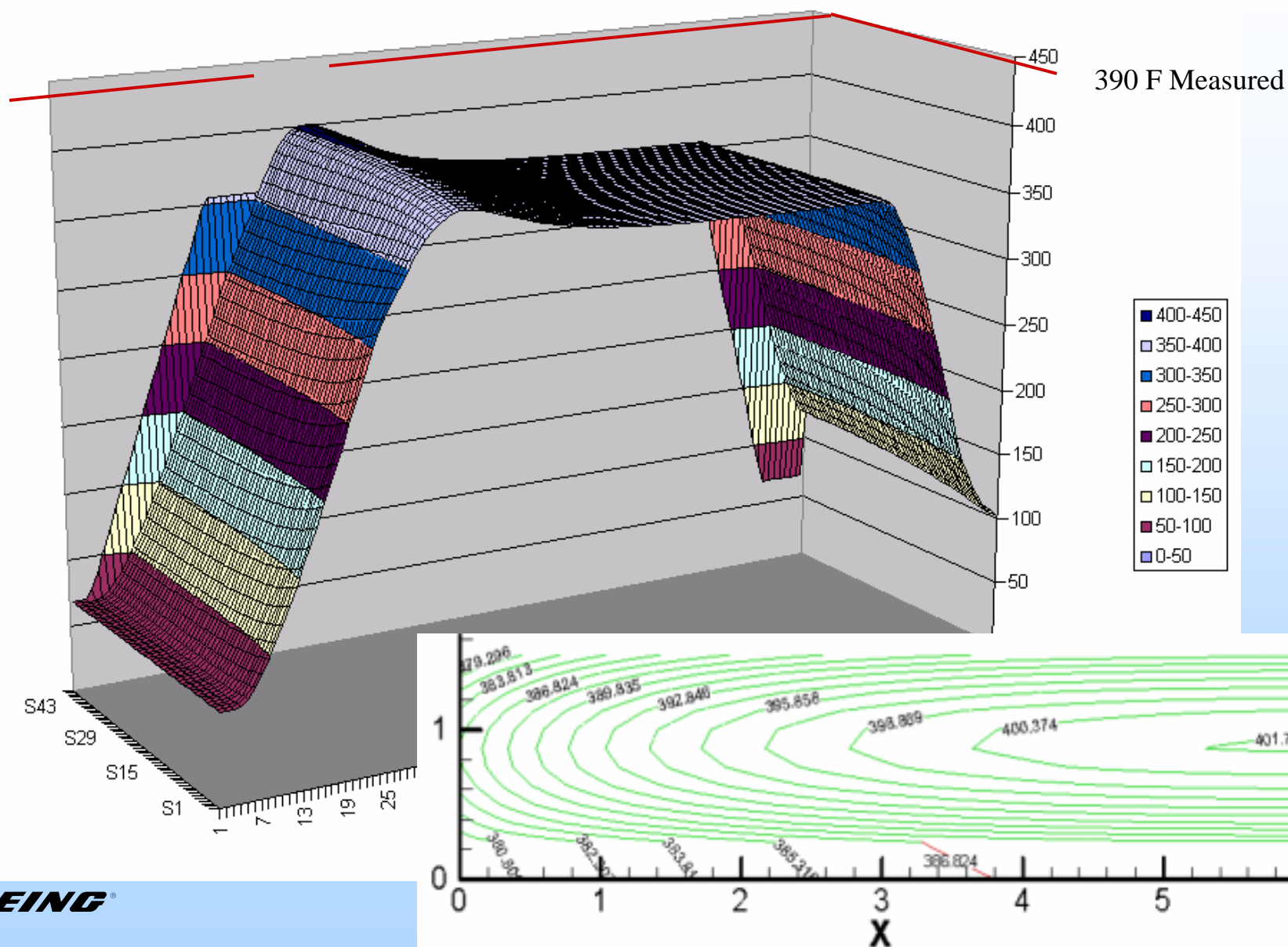


977-3 w/8552 kinetics & 977-3 HRx 5" thick



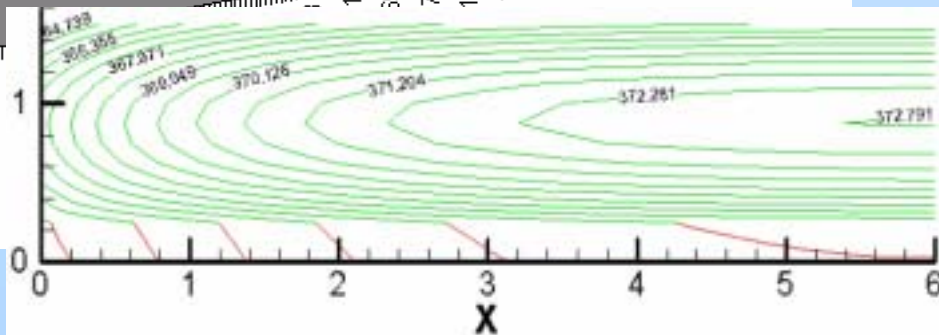
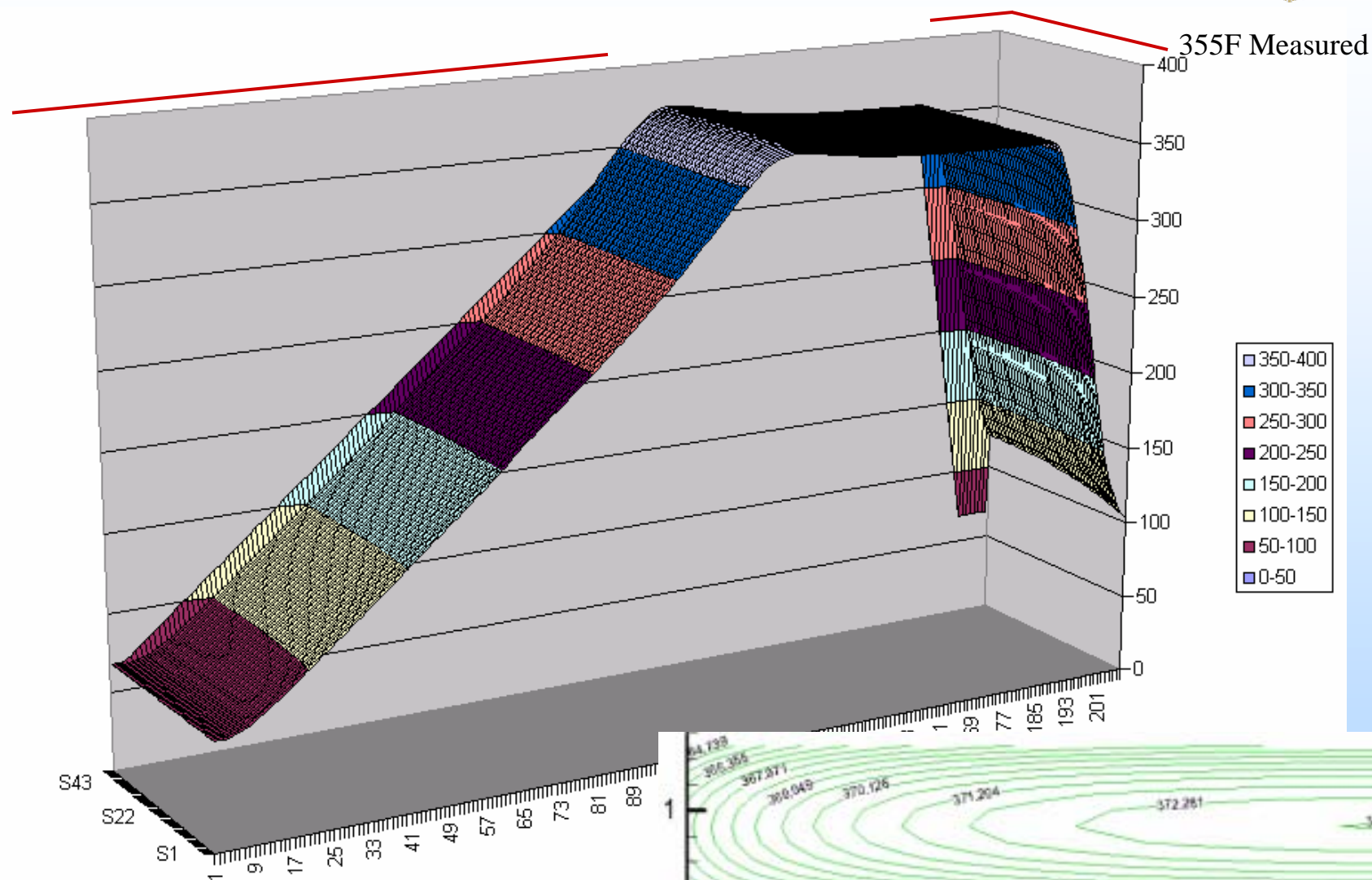


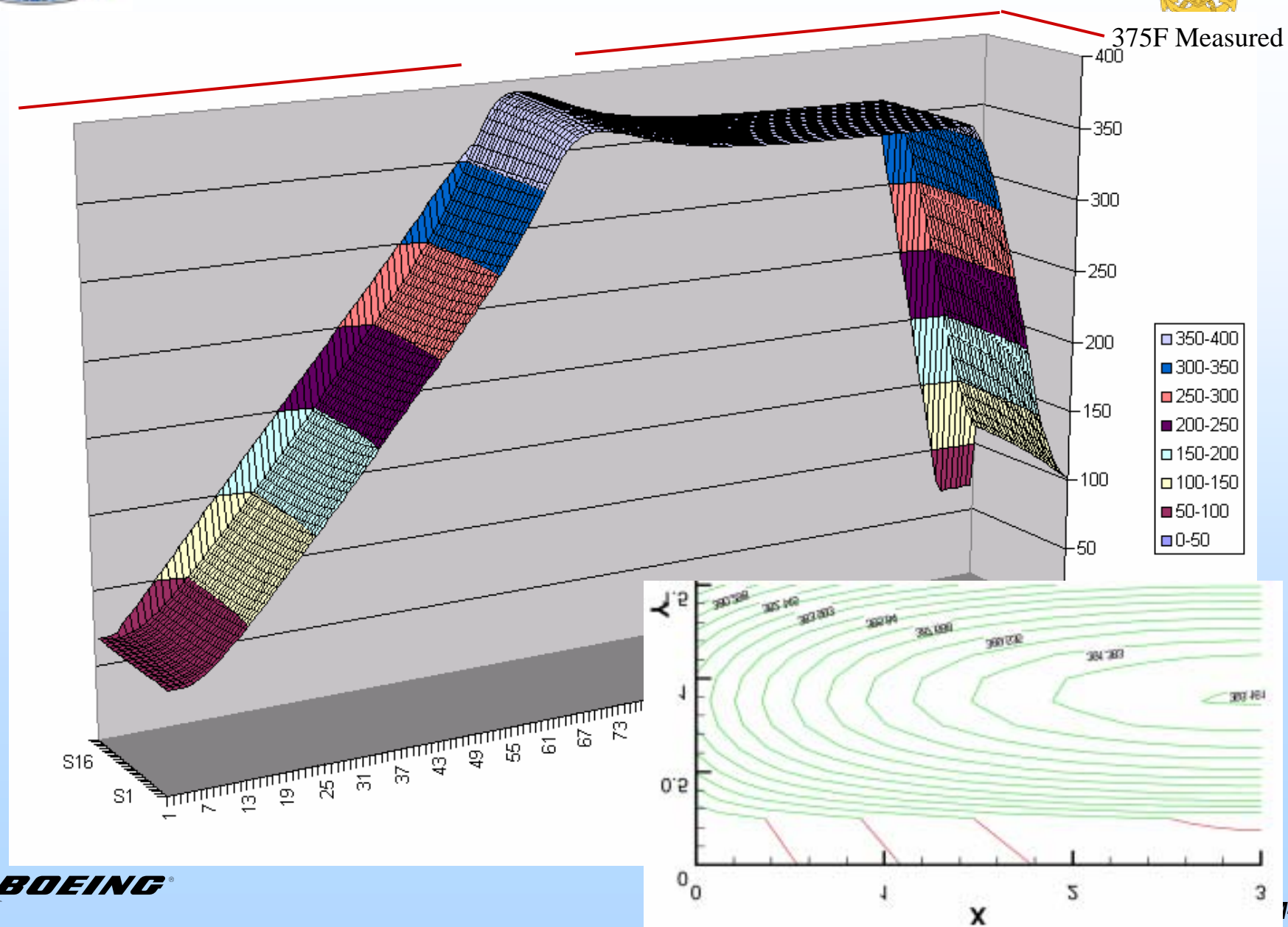
977-3 1.25" thick F18 run 1





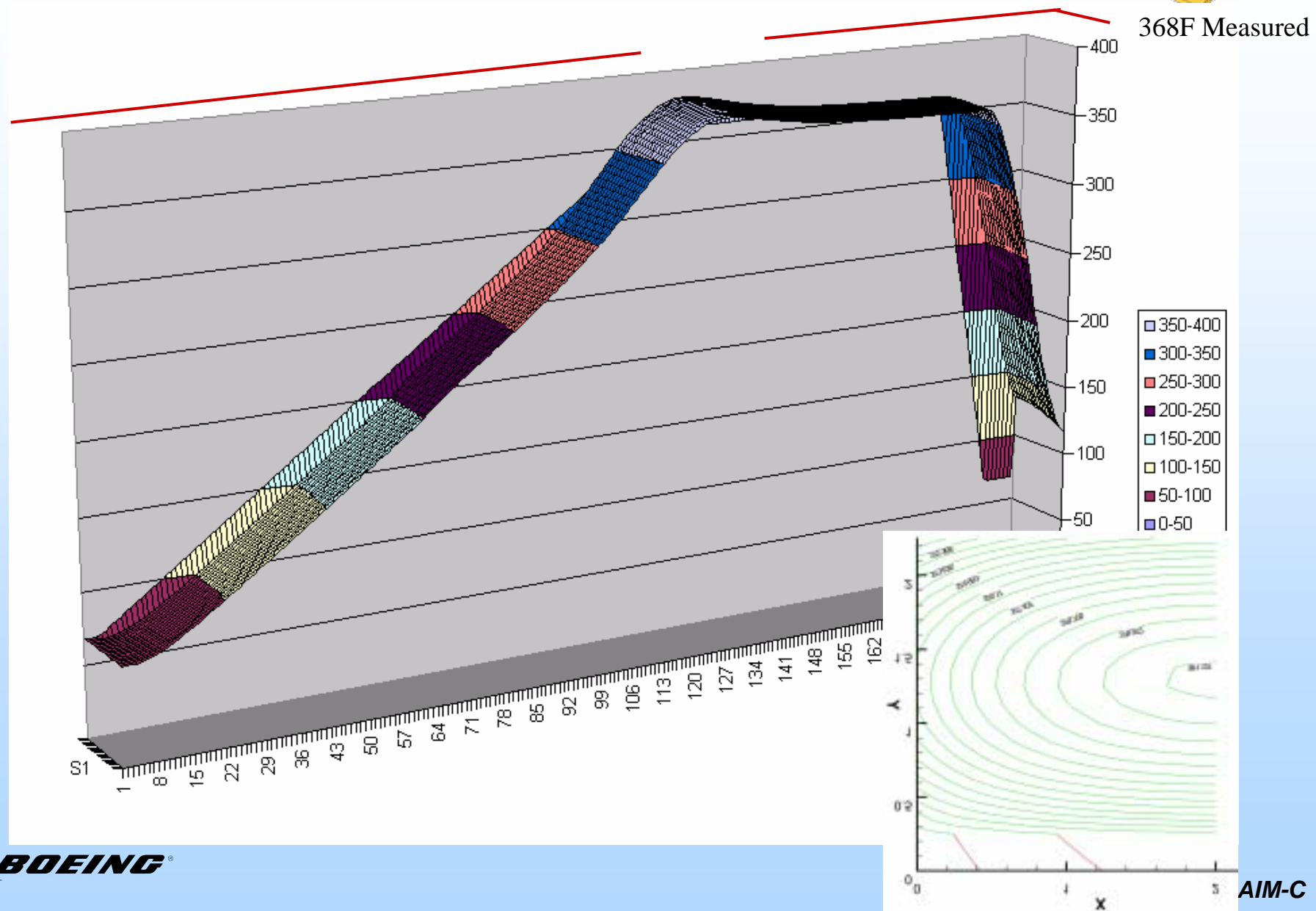
977-3 1.25" thick F18 run 2





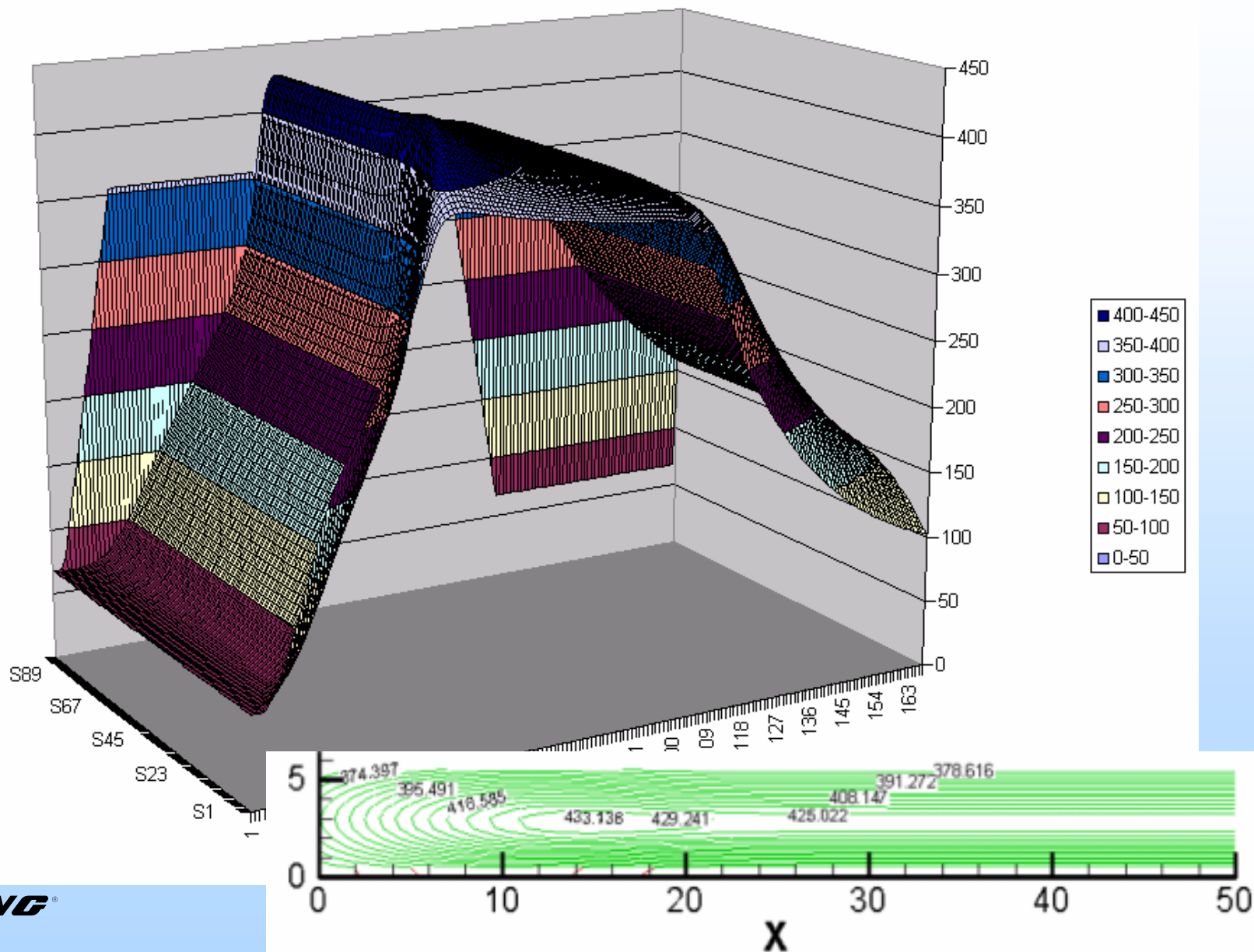


977-3 2" thick F18 run 4



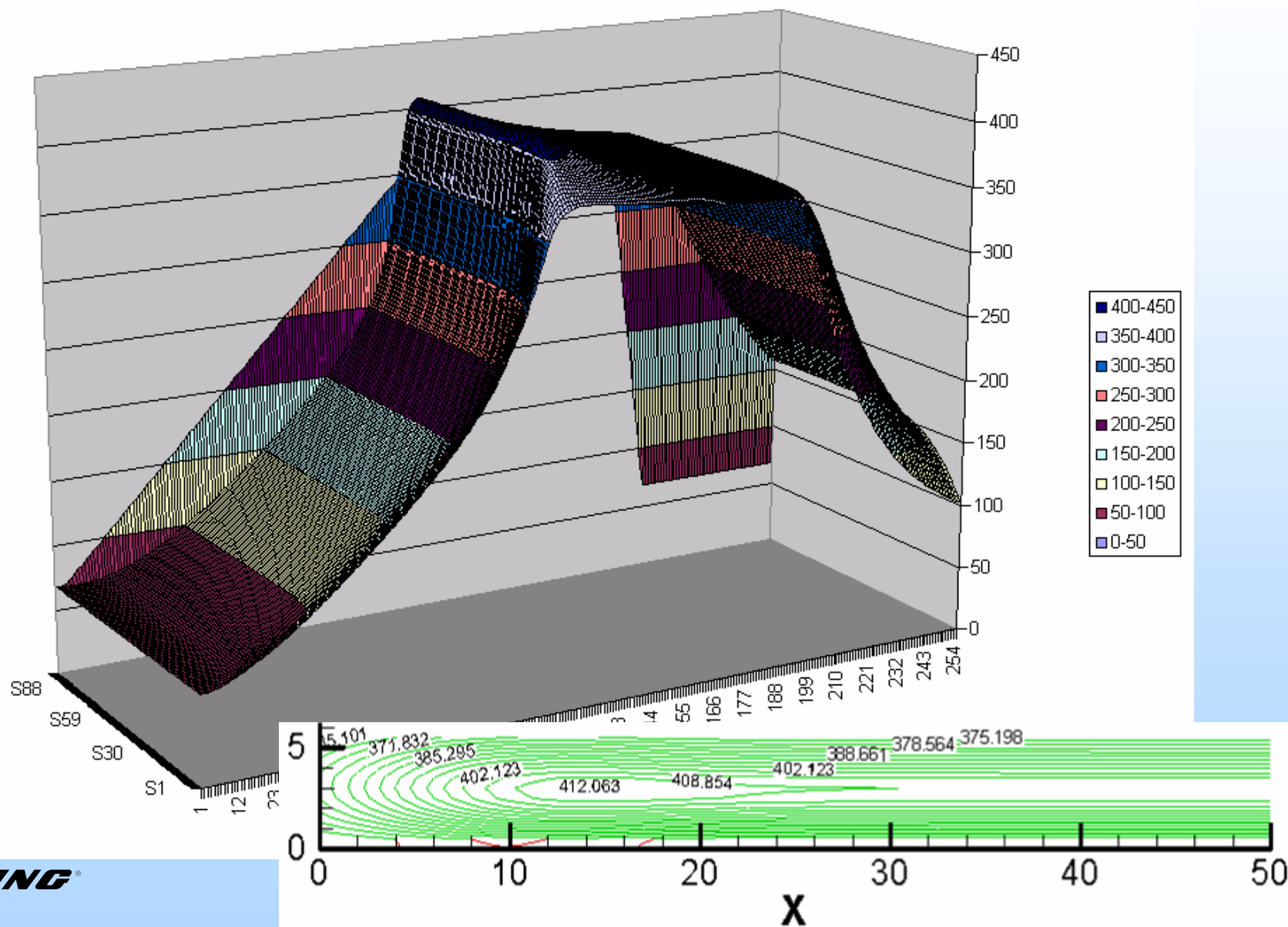


BMS8-276 5" thick 4.25F ramp to 355F, 85 PSI

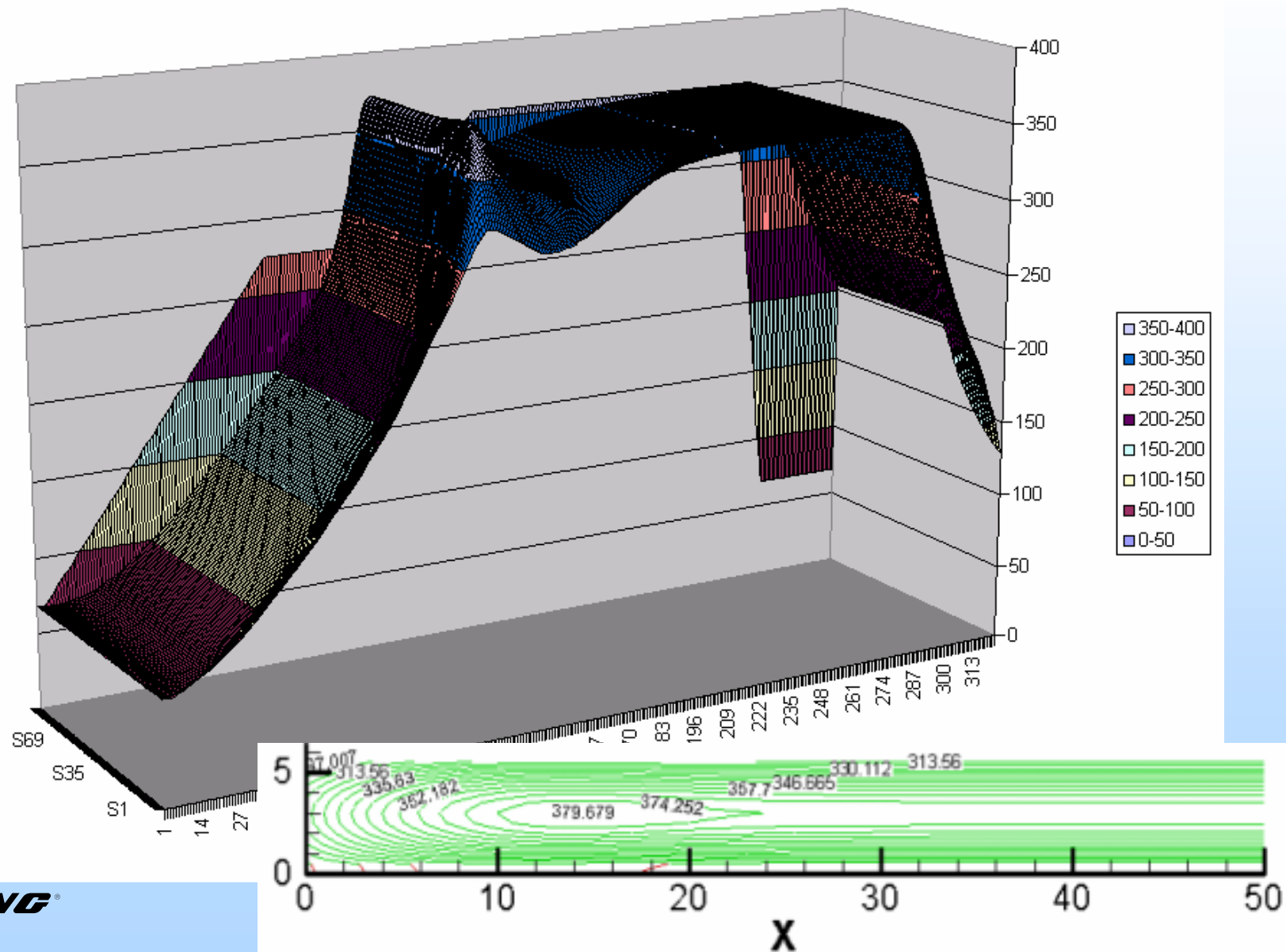




BMS8-276 5" thick 0.5 ramp to 355F, 85 PSI



BMS8-276 5" thick 0.5 ramp to 355F, 85 PSI with 2 hour 275 hold





AIM-C

Now and the Future



- AIM C Modules Providing Tangible Benefits Now
 - Sonic Cruiser – Thick Laminate Processing
 - UCAV CAI T4 – VARTM skin dimensional control
 - Exposure and Confidence in Modules and Models
- AIM-C Modules and Methodology – The Future
 - Link Modules and Data Familiar to Engineering Community
 - Drive with Proven Methodology
 - Directed Testing
 - Enhance Test Results with Model Extrapolation/Interpolation
 - Heuristics for Comparison to Historical Database
 - Statistical Evaluation
 - Document Results
 - Reduce Materials Insertion Time



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